MINERALOGY OF THE LAKE ZONE, THOR LAKE, N.W.T.
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D. Robert Pinckston
Dorian G.W. Smith
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NWT GEOLOGY DIVISION - NAP
Box 1500 - Yellowknife

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INTRODUCTION

An economically significant Be, Nb, Ta, REE, Y, Zr and Ga deposit, known as the Thor Lake rare-metal deposit, lies approximately 100 km southeast of Yellowknife and about five km north of Great Slave Lake. Mineralisation is associated with a peralkaline pluton containing the Thor Lake syenite and Grace Lake granite which is, in turn, part of a larger body known as the Blachford Lake Intrusive Suite. Five zones in this deposit have been identified: the T, R, S, Lake and Fluorite zones. The mineralogical study of the Lake zone is the purpose of the present research.

GENERAL GEOLOGY

The Blachford Lake Complex is a circular (25 km diameter) body of genetically related rocks at the southern margin of the Slave Province along the East Arm of Great Slave Lake. The complex is early Proterozoic in age, and has intruded Archean Yellowknife Supergroup greywackes, turbidites and their metamorphic equivalents (Davidson, 1978). Bowring et al. (1984) have dated the complex and determined an age range from 2100 to 2200 Ma.

Field studies in the summer of 1987 confirmed the existence of a diverse suite of rocks and in the process led to the discovery of previously unreported anorthosites and minor pyroxenites within the Caribou gabbros and leucogabbros on the western side of the complex. Also present are the mildly-alkaline Mad Lake and Hearne Channel

granites and the Whiteman Lake quartz syenite. The eastern portion of the complex contains the dominant peralkaline Grace Lake granite and Thor Lake syenite, although a substantial body of nepheline syenite has recently been discovered lying beneath the rare metal mineralisation of the Lake zone. These silica undersaturated rocks have been intersected at a depth of about 600-700' in three separate drill holes, all a minimum of one km from each other.

In terms of temporal relationships, it is certain that the western gabbros, leucogabbros, syenites and granites are older and less alkaline than the eastern peralkaline granites and syenites. Contact relationships between the Grace Lake granite and the Thor Lake syenite are ambiguous, although a porphyritic syenite dike was noted and appears to have intruded the nearby granite, implying a younger age for the Thor Lake syenite. It can, then, be suggested that the silica content decreases with time, going from granite to syenite and ending with nepheline syenite.

Hosted by the Thor Lake syenite, the Lake zone is approximately triangular and covers an area of about two square kilometers of altered and brecciated rock. Two major rock types are present: a feldspathic outer zone with abundant potassium feldspar and albite, and an inner core composed dominantly of albite, micas, quartz, magnetite and hematite (the last three minerals generally have replaced pyroxene grains). There are local pockets of zircon, columbite, magnetite or allanite-(Ce) throughout. A summary

of these and other ore-bearing minerals will be discussed below.

MINERALOGY

A number of minerals have been found both in the Lake zone and the nepheline syenite. Within the Lake zone, microcline, albite, biotite and quartz are the major rock-forming minerals. Pyroxenes have, in all cases, been replaced by quartz-magnetite or quartz-hematite-carbonate assemblages. Microclinization and albitization were followed by the formation of chlorite and biotite and by late-stage fluorite and carbonates. In terms of economic mineralogy, Nb and rare earth-bearing minerals are of prime importance. Of secondary importance are the Y, Ta, Ga and Zr-bearing minerals. The following is a brief description of the minerals of economic interest found so far.

The rare earth elements (REEs) are found in a number of minerals, the most common being allanite-(Ce). In some cases, the allanite-(Ce) contains appreciable amounts of Mn. Generally it is anhedral and somewhat altered or brecciated, indicating formation early in the paragenetic sequence. The bastnaesite group minerals (bastnaesite-(Ce), parisite-(Ce), rontgenite-(Ce) and synchysite-(Ce)) are also common, both as individual grains or polycrystals and as replacement minerals of the allanite-(Ce). The rare earth fluorcarbonates were the last REE-bearing minerals to form in the Lake zone. A third REE-bearing mineral of importance is monazite-(Ce). It has formed as a late stage mineral,

filling voids left by zircons and occurring as vein material.

Nb and Ta have been identified in at least three minerals: ferrocolumbite, fergusonite-(Y) and an unidentified U, Nb-silicate. The former, which is low in Mn and Ta, generally forms small (10-20u), needle-like grains as either radial 'pin-ball' aggregrates or individual needles. The fergusonite-(Y) grains are even smaller (5-10u) and are thought to be, in places, an important contributor to elevated Nb and Y contents. The third Nb-bearing mineral is a recently discovered U,Nb-silicate. This mineral is found as small (2-5u), opaque grains either as aggregrates or intergrown with ferrocolumbite and rimmed by hematite.

Xenotime-(Y), fergusonite-(Y) and zircon contribute to the Y enrichment. Xenotime-(Y) is thought to be concentrated only in certain areas and is probably unimportant. Zircon is exceedingly abundant within the Lake zone and is the only contributor to enriched Zr contents. The zircons were also found to contain upwards of 3 wt% Y_2O_3, 2 wt% HfO_2 and have minor amounts of the middle to heavy REEs. And because of the preponderance of zircons, they are likely to be an important contributor to enriched Y, Zr and possibly Hf values. Ga is concentrated in the feldspars but is also found in some of the micas (Hudson, 1987).

As the nepheline syenite is a recent discovery, several minerals new to the area have been discovered. In addition to the rock-forming minerals nepheline, potassium feldspar, albite and acmite, moderate amounts of sodalite, pectolite and analcite and minor amounts of catapleiite, eudialyte, andradite, manganoan allanite-(Ce), willemite, mesolite and natrolite have been found. Several minerals of minor abundance await identification.

The rock-forming minerals such as acmite and albite were found to be chemically very pure, that is, very little Ca or Al resides in acmite and no Ca or K is found in the albite. Nepheline, though, is found to be in various states of alteration due to late stage hydrothermal activity. Many grains have lost alkalis and are now a mixture of secondary, micaceous minerals that impart a red or green colour to the grains. Other nepheline grains have reacted with neighbouring albite crystals in the presence of water to form rims of analcime. It is at the interface between the analcime and nepheline that blue cathodoluminescent rims were noted under the electron beam. By analogy with blue cathodoluminescence on albite in T zone rocks, it was suspected that these blue rims result from minor amounts of Ga (de St. Jorre and Smith, 1988). Two separate Ga scans were done, but neither showed any concentrations of that activator element. Sodalite cathodoluminesces a dull purple, as do many silicates, while pectolite shows a

brilliant yellow probably due to minor Mn, a common activator in other silicates.

Sodalite or calcite and fluorite-rich 'xenoliths' have been found within the nepheline syenite. Approximately 3-5 cm in size, these xenoliths contain a strange assortment of minerals including abundant metasomatic andradite and another unidentified Ca-Fe silicate. There is no doubt they are exotic and association with fresh calcite suggests they might have formed by fenitisation (due to a carbonatite?) at depth.

ORIGIN OF MINERALISATION

The Blachford Lake intrusive suite includes rock types typically found in many alkaline ring complexes. Thus comparisons can be drawn with the Nigerian ring complexes (Bowden, 1985; Bowden et al., 1987), the Chilwa province of Malawi (Woolley and Jones, 1987), the Velasco province of eastern Bolivia (Fletcher and Beddoe-Stephens, 1987) and, if carbonatites of some significance can be found at depth, the Kisingiri and Usaki districts in the Kenya rift area (Le Bas, 1977).

Lithologies found include a sequence of marginal gabbros, pyroxenites, anorthosites and leucogabbros followed by saturated to oversaturated alkaline (or peralkaline) granites and syenites all in a circular or ring-shaped outline. Ring dikes, especially of granitic or syenitic composition, are also common features. The so-called Rim

syenite is a steeply dipping, fayalite-hedenbergite syenite that appears to have the characteristics of a ring dike. A volcanic pile consisting of trachytes, rhyolites, etc. commonly overlies such sequences but, at Thor Lake, deep level erosion has totally removed such rock types.

The five zones of mineralisation identified so far are rather complex and difficult to interrelate. For the most part, their origin can be ascribed to various metasomatic reactions within these so called A-type granites and syenites. The following generalised model can be envisaged. After emplacement of the marginal gabbros, anorthosites, granites and syenites, the Grace Lake granite intruded and overprinted portions of those rocks. Next, as is common in alkaline ring complexes, a zoned syenite or granite (Thor Lake syenite) was emplaced. The outer portion is fayalitic while the inner part is dominantly an arfvedsonite or biotite syenite.

The Thor Lake syenite was probably emplaced in such a way that a 'bump' or fold formed (i.e., present day Lake zone) thereby creating a trap for mineralising fluids. Postmagmatic metasomatism proceeded as follows: initial, intense potassic metasomatism and albitisation followed by acid metasomatism or greisenisation (T-zone only). As suggested by Bowden (1985), the principal economic minerals associated with this type of alteration include columbite, monazite-(Ce), xenotime-(Y) and fergusonite-(Y), all of which are present in the Lake zone. In addition, Pollard

(1986) noted the tremendous influence postmagmatic alteration can have on rare-metal mineralisation especially in peralkaline granites and syenites.

Immediately following or possibly contemporaneous with these metasomatic changes, a nepheline syenite was intruded and because of structural weaknesses induced by the alteration, these silica-undersaturated rocks forced their way towards the site of mineralisation. The nepheline syenite probably did not contribute to the final phase of rare metal enrichment. Instead, the host Thor Lake syenite-Grace Lake granite system may be the source for the Lake zone deposit as they are known to contain elevated incompatible element (i.e., Nb, REEs, Zr, Rb and Be) concentrations (Davidson, 1982). The nepheline syenite appears miaskitic and as such would not contain significant levels of incompatible elements. Whole rock and trace element analyses should be completed and would help in solving the dilemma.

If the nepheline syenite is a late stage intrusion, then adjacent fenite zones should be present. This may be the case but direct evidence for carbonatite or nepheline syenite fenitisation is lacking. Typical fenitisation effects such as the disappearance of quartz and the formation of alkali amphiboles or pyroxenes as described at other classic localities (Sokli, Finland (Vartiainen and Woolley, 1976); Fen, Norway (Bowen, 1924)) are not found in the Lake zone. The small xenoliths rich in fluorite,

andradite and calcite mentioned earlier suggest fenitisation has occurred but at some depth within the intrusion.

To complicate matters, late stage hydrothermal activity shown by altered nepheline grains and increased oxygen fugacities shown by pervasive hematization, has clouded all contact relationships and made observations of postmagmatic mineralogical changes difficult.

CONCLUSION

Unlike the T-zone, the Lake zone does not contain appreciable amounts of Be or Li but in an economic sense this is compensated for by the presence of significant Zr, Nb, Ga, Y and LREEs. Minerals of economic importance include allanite-(Ce), monazite-(Ce), the bastnaesite group minerals, ferrocolumbite and zircon. The nepheline syenite contains no such economically important minerals although minor catapleiite and eudialyte have been noted.

The origin of the rare-metal enriched Lake zone is not clear. Most likely, the incompatible element-rich Thor Lake syenite in combination with late-stage K and Na metasomatism, were responsible for the existence of the present-day Lake zone. Alternatively, it is possible, but unlikely, that the Lake zone is a large fenite and that rare-metal mineralisation resulted from the underlying nepheline syenite. Although nepheline syenite and carbonatite fenitisation can cause similar mineralogical and petrochemical changes to those produced by granite

associated metasomatism, there is no evidence to suggest fenites are prevalent in this deposit.

With the discovery of a greater variety of lithologies within the westerly mafic and felsic igneous sequence and of silica undersaturated rocks beneath the Lake zone, ideas about the area are constantly evolving. With continued work more features crucial in piecing together the area's geological history should be found.

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